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A COMPARISON OF THE LATERAL CONTROLLABILITY WITH FLAP AND PLUG AILERONS ON A SWEPTBACK-WING MODEL

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SUMMARY

An investigation has been conducted to compare the dynamic lateral control characteristics provided by step plug ailerons with those provided by conventional flap ailerons on a sweptback-wing model. The model used had a 38° sweptback wing with an aspect ratio of 3 and a taper ratio of 0.5. The static stability and control characteristics of the flight test model were determined from force tests and the lag characteristics of the ailerons were determined from roll-free stand tests. Flight tests of the model were made through a range of lift coefficient from 0.6 through the stall by using the data obtained from the force tests to establish the flight test conditions. At each lift coefficient in the flight test range the flap ailerons were adjusted to produce the same static rolling moment as was obtained by maximum projection of the plug ailerons.

The controllability of the model was more satisfactory with plug ailerons alone than with flap ailerons alone except at lift coefficients below about 0.7. At the lower lift coefficients the time lag from full control deflection to maximum rolling acceleration caused by the plug ailerons was more objectionable than the slight adverse yawing caused by the flap ailerons; whereas, at the higher lift coefficients, the loss of rolling effectiveness caused by the large adverse yawing moments of the flap ailerons was more objectionable than the lag of the plug ailerons. At the stall, the model could be controlled satisfactorily with the plug ailerons alone or with the flap ailerons and rudder but could not be controlled satisfactorily with the flap ailerons alone.

INTRODUCTION

Recent research has indicated that spoilers may offer several advantages over conventional flap ailerons for lateral control with sweptback wings. Some of these advantages are: favorable, instead of

adverse, yawing moments; greater rolling moments at high angles of attack; higher aileron reversal speeds due to smaller wing twisting moments; the possibility of smaller control forces; the possibility of using the entire trailing edge of the wing for full-span lift flaps; and increased rolling effectiveness when full-span flaps are deflected. Investigations to determine the static control characteristics of various spoiler control configurations on swept wings have been made by the National Advisory Committee for Aeronautics (for example, reference 1). In order to determine the dynamic control characteristics of spoiler ailerons on sweptback wings, the present investigation was made in the Langley free-flight tunnel with a flying model having the optimum spoiler plan-form configuration determined from the tests reported in reference 1.

The model used in the free-flight-tunnel investigation had a 38° sweptback wing with an aspect ratio of 3 and taper ratio of 0.5. The model had both flap ailerons and step plug ailerons. The investigation consisted mainly of flight tests over a range of lift coefficient from 0.6 through the stall to obtain a comparison of the controllability of the model with the two types of ailerons. Tests to determine the time lag from full control deflection to maximum acceleration were made with the model mounted on a stand that allowed freedom only in roll. The static stability and control characteristics of the model were determined from force tests; the data from these tests were subsequently used to determine the conditions for the free-flight tests.

SYMBOLS

The forces and moments are referred to the stability axes, which are defined as an orthogonal system of axes intersecting at the airplane center of gravity in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. A diagram of these axes showing the positive direction of forces and moments is presented in figure 1.

The symbols and coefficients are defined as follows:

m	mass of model, slugs
S	wing area, square feet
b	wing span, feet
c	wing chord, feet
$\bar{c}$	wing mean aerodynamic chord, feet

k_X	radius of gyration of model about body X-axis, feet
k_Y	radius of gyration of model about body Y-axis, feet
k_Z	radius of gyration of model about body Z-axis, feet
V	airspeed, feet per second
ρ	mass density of air, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\rho V^2/2\right)$
α	angle of attack, degrees
β	angle of sideslip, degrees $(-\psi)$
ϕ	angle of bank, degrees
$\dot{\phi}$	rolling angular velocity, degrees per second
$\ddot{\phi}$	rolling angular acceleration, degrees per second per second
C_L	lift coefficient (Lift/qS)
C_D	drag coefficient (Drag/qS)
C_Y	lateral-force coefficient (Lateral force/qS)
C_m	pitching-moment coefficient (Pitching moment/$qS\bar{c}$)
C_l	rolling-moment coefficient (Rolling moment/qSb)
C_n	yawing-moment coefficient (Yawing moment/qSb)
C_{Y_β}	rate of change of lateral-force coefficient with angle of sideslip, per degree $(\partial C_Y/\partial\beta)$
C_{l_β}	rate of change of rolling-moment coefficient with angle of sideslip, per degree $(\partial C_l/\partial\beta)$
C_{n_β}	rate of change of yawing-moment coefficient with angle of sideslip, per degree $(\partial C_n/\partial\beta)$
$\delta_{a_{flap}}$	total aileron deflection of flap ailerons, degrees
$\delta_{a_{plug}}$	projection of plug ailerons, percent chord

δ_r rudder deflection, degrees

δ_e elevator deflection, degrees

APPARATUS

The investigation was conducted in the Langley free-flight tunnel which is equipped for testing free-flying dynamic models. A complete description of the tunnel and its operation for testing models in free flight and by force tests is given in references 2 and 3, respectively.

A three-view sketch of the model used in the present investigation is presented in figure 2. The model had the following geometric characteristics:

Wing area, sq ft	6.75
Span, ft	4.50
Aspect ratio	3.00
Taper ratio	0.50
M.A.C., ft	1.50
Center-of-gravity location, percent M.A.C.	0.25
Airfoil section	Rhode St. Genese 35

The wing was swept back 38° and was equipped with half-span, 20-percent-chord, plain flap ailerons and step plug ailerons of 0.60 semispan, which were determined as optimum configurations from tests reported in reference 1. The step plug ailerons consisted of 6 segments, each of which was 0.10 semispan, with the center of each segment on the 0.70-chord line and perpendicular to the plane of symmetry of the model. Each segment fitted into a slot in the wing in such a way that the slot in the wing was closed when the spoiler was in the retracted or neutral position and open when the spoiler was projected above the upper surface of the wing. A cross section of the wing giving details of the plug aileron is shown in figure 2. The maximum extension of the plug ailerons was 0.06 of the local chord.

The control used on the model during the flight tests was a flicker (full-on or full-off) system. During any one particular flight, the control deflections in the full-on position were constant and the amount of control applied to the model was regulated by the length of time the controls were held rather than by the magnitude of the control deflections. The control system was arranged so that lateral control of the model could be obtained through use of either the flap ailerons or the plug ailerons and the change from one type of control to the other could be effected in flight so that a direct comparison could be made of the controllability provided by the two types of controls. The rudder

control could be used with either of the aileron control systems or could be held fixed in a trim position during flight.

The mass characteristics of the model were:

Mass, m, slugs	0.838
Nondimensional radius of gyration about longitudinal axis, k_X/b	0.195
Nondimensional radius of gyration about lateral axis, k_Y/b . . .	0.369
Nondimensional radius of gyration about vertical axis, k_Z/b . .	0.405

DETERMINATION OF STATIC STABILITY AND CONTROL

CHARACTERISTICS OF FLIGHT TEST MODEL

Force tests were made at a dynamic pressure of 2 pounds per square foot to determine the static lateral stability and control characteristics of the model and to establish the flight test conditions. The aileron control characteristics were determined for both types of ailerons by varying the aileron deflection at constant angles of attack. The rudder control characteristics were measured so that in flight tests the rudder deflection could be adjusted to make the yawing moments of the flap aileron and rudder combination equal to those of the plug ailerons alone. The rudder control characteristics were determined by varying the rudder deflection with the model at an angle of attack of 0°. The yawing moments due to rudder deflection were assumed to be constant over the angle-of-attack range. The static-lateral-stability derivatives of the model were determined from measurements of force and moment coefficients at 5° and -5° yaw.

The results of the force tests are presented in figures 3 to 6. Figures 3 and 4 show the static longitudinal and lateral stability characteristics of the model with all of the controls undeflected. Figures 5 and 6 show the static lateral control characteristics of the model with each of the two types of ailerons.

The data of figure 5 show that the plug ailerons produced essentially the same rolling moment for all angles of attack covered in the tests. The plug ailerons also produced approximately the same favorable yawing moments at angles of attack of 16° or less but produced slightly adverse yawing moments at an angle of attack of 20°. Figure 5 also indicates that no reversal of effectiveness of the plug ailerons occurred at small projections, a result which is often a characteristic of unslotted spoiler ailerons. A reversal of control effectiveness at small projections was originally a characteristic of the plug ailerons on this model but was eliminated by fairing the lower forward slot lip. This method of

eliminating the reversal of effectiveness at small projections was indicated in unpublished data obtained in the Langley 7- by 10-foot tunnel.

The static control characteristics of the flap ailerons are shown in figure 6. These data show a large reduction in aileron rolling moment with increase in angle of attack. Also, an increase in the adverse aileron yawing moment with increase in angle of attack was evident.

Comparison of the data of figures 5 and 6 shows that the flap ailerons at 40° deflection could produce much larger rolling moments than the plug ailerons at low angles of attack. Larger rolling moments could be obtained from plug ailerons, however, by using larger plug-aileron projections than were possible with the present model. One device that has been proposed for increasing the projection of plug ailerons is a telescoping or double-extension plug. In some cases, the total flap-aileron deflection required to give rolling moments equal to those of the plug ailerons exceeded the 40° covered in the force tests. In these cases the data from the force tests were extrapolated by use of the trends of data for similar wings with larger aileron deflections which had been previously investigated in the Langley free-flight tunnel. These extrapolations are shown by dashed lines in figure 6.

The aileron deflections used at various flight lift coefficients are shown in figure 7. Figure 7 also shows the static rolling and yawing moments for both types of ailerons for the flight-test conditions. The rolling-moment and yawing-moment data were extrapolated to the higher lift coefficients by using the trends indicated by the data for a similar model previously tested in the Langley free-flight tunnel. These extrapolations are indicated by the dashed parts of the curves in figure 7. These data indicate that at the highest flight lift coefficients, it was impossible to obtain as large rolling moments with the flap ailerons as with the plug ailerons because of mechanical limitations to the deflection of the flap ailerons.

DETERMINATION OF TIME LAG CHARACTERISTICS OF THE FLIGHT TEST MODEL

Measurements of the lag from full control deflection to maximum rolling acceleration of the two types of ailerons were made with the model mounted on a stand at an angle of attack of 10° and free only to roll about the longitudinal body axis. For these tests the deflection of the flap ailerons was adjusted to give the same static rolling moment as was obtained by maximum projection of the plug ailerons. Motion-picture records were made of both right and left rolls with the flap ailerons and the plug ailerons.

Figure 8 shows typical time histories of the rolling motions of the model. The records of control position and angle of bank were read directly from motion-picture records taken at 48 frames per second. The curves for rolling velocity and acceleration were obtained by taking slopes of the angle-of-bank curves to obtain rolling velocity and of the rolling-velocity curves to obtain rolling acceleration. Because of the relatively long time increments between successive frames of the movie records (about 0.02 sec), the angle-of-bank curve for the first part of the motion could not be faired with sufficient accuracy for even reasonably accurate determination of the rolling velocity and acceleration for this period of time. Hence, rolling-velocity and acceleration data are not presented for the first 0.04 second. The data of figure 8 indicate, however, that the flap ailerons produced maximum acceleration at or before the time at which full deflection was reached and that the plug ailerons produced maximum acceleration about 0.1 second after full projection was reached. A relatively large time lag such as that encountered with the plug ailerons on the sweptback wing has previously been found for forward spoiler-aileron locations on unswept wings, but this lag decreased as the spoiler control was moved rearward along the chord. (See, for example, reference 4.)

If the model is considered as a $\frac{1}{10}$-scale model of an airplane, the lag measurements indicate that the airplane would require less than 0.1 second to reach maximum rolling acceleration with flap ailerons and would require about 0.3 second to reach maximum rolling acceleration with plug ailerons. Comparison of these scaled-up values of time lag with the lag requirements of reference 5 indicates that the flap ailerons would easily satisfy these requirements and that the plug ailerons would barely satisfy the requirements.

SCOPE OF FLIGHT TESTS

Flight tests of the model were made for a range of lift coefficient from 0.6 to 1.4 and through the stall. At each test lift coefficient and at the stall, flights were made with the following control combinations: flap ailerons alone, flap ailerons and rudder, and plug ailerons alone. In addition, some isolated tests at very high lift coefficients were made with plug aileron and rudder. For all of the flights with plug-aileron control, maximum plug-aileron projection was used. For all of the flights with the flap ailerons, the aileron deflection used for control was adjusted to provide the same rolling moment as the plug ailerons at the same lift coefficient (fig. 7). For all of the flights with the rudder linked to move with the flap ailerons, the rudder deflection was adjusted so that the yawing moments of the flap aileron and rudder combination were the same as those of the plug ailerons alone.

FLIGHT TEST RESULTS AND DISCUSSION

Qualitative ratings of the controllability of the model made by the pilot are presented in table I for each of the lateral control combinations used in the flight tests. From the flight tests a direct comparison of the controllability afforded by the two types of ailerons was obtained for the rudder-fixed condition. Aileron control characteristics are customarily evaluated for this condition (reference 4). A direct indication of the effect of the relative time lag of the two types of ailerons was obtained in the flight tests from a comparison of the controllability produced by the plug ailerons alone with that produced by the flap ailerons and rudder combination.

Plug Ailerons

The controllability ratings of table I show that, with the plug ailerons alone, the lateral control characteristics of the model were considered satisfactory over the speed range covered in the flight tests although the controllability was slightly less satisfactory at lift coefficients above a value of about 1.3 than at lower lift coefficients. At the stall the controllability was satisfactory although some adverse yawing was evident. When the rudder was used in conjunction with the plug ailerons to counteract the adverse yaw at high lift coefficients, the controllability of the model was about as satisfactory as that of the plug ailerons alone at the lower lift coefficients. At lift coefficients below a value of about 1.2, the favorable yawing moments of the plug ailerons opposed the adverse yawing moments due to rolling so that there was essentially no yawing to influence the aileron rolling effectiveness. At lift coefficients above a value of about 1.2, however, the adverse yawing moments of the plug ailerons combined with the positive effective wing dihedral to cause rolling moments which opposed those of the ailerons.

Although a detrimental effect of excessive favorable aileron yawing moments on the lateral control characteristics had been anticipated at low lift coefficients, no such detrimental effect was encountered in the present tests. Since these tests did not include very low lift coefficients, however, no definite answer to this problem was obtained.

Flap Ailerons

The controllability ratings of table I show that, with the flap ailerons alone, the lateral control characteristics of the model were considered satisfactory at lift coefficients below a value of about 0.9, but were unsatisfactory at higher lift coefficients and that the model could not be controlled at a lift coefficient of 1.4 or at the stall.

This result is attributed primarily to the yawing moments of the flap ailerons which were adverse at all lift coefficients and became increasingly adverse as the lift coefficient increased. At the lower lift coefficients the adverse yawing due to aileron deflection was insufficient to cause a substantial decrease in the rolling effectiveness of the ailerons, but at the higher lift coefficients this adverse yawing caused the rolling effectiveness to be greatly reduced. This analysis is substantiated by the results of the flight tests with the rudder used in conjunction with the ailerons (table I). These results show that the controllability of the model was satisfactory over the entire flight test range.

Comparison of Plug and Flap Ailerons

Comparison of the controllability ratings of table I shows that with aileron alone the controllability of the model was more satisfactory with the plug ailerons than with the flap ailerons at all flight lift coefficients except the lowest $\left(C_L = 0.6\right)$. These characteristics result primarily from the differences in time lag and aileron yawing moments. At the low lift coefficients, the greater lag of the plug ailerons was more objectionable than the slight adverse yawing caused by the flap ailerons; whereas, at the higher lift coefficients, the loss of rolling effectiveness caused by the large adverse yawing moments of the flap ailerons was more objectionable than the greater lag of the plug ailerons.

The data of table I also show that the controllability of the model was, in general, slightly better with the flap ailerons and rudder than with the plug ailerons alone. This result indicates that, with equal rolling and yawing moments for both types of ailerons, the time lag of the plug ailerons causes the controllability of the model to be slightly less satisfactory.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
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1. Schneiter, Leslie E., and Watson, James M.: Low-Speed Wind-Tunnel Investigation of Various Plain-Spoiler Configurations for Lateral Control on a 42° Sweptback Wing. NACA TN 1646, 1948.

2. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN 810, 1941.

3. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of the Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR 3D17, 1943.

4. Shortal, J. A.: Effect of Retractable-Spoiler Location on Rolling- and Yawing-Moment Coefficients. NACA TN 499, 1934.

5. Anon.: Flying Qualities of Piloted Airplanes. U.S. Air Force Specification No. 1815-B, June 1, 1948.

TABLE I

QUALITATIVE RATINGS OF LATERAL CONTROL CHARACTERISTICS OF MODEL WITH VARIOUS COMBINATIONS OF LATERAL CONTROLS

C_L	Controllability[1]			
	Plug ailerons alone	Flap ailerons alone	Plug ailerons and rudder	Flap ailerons and rudder
0.6	A-	A	--	A+
.8	A-	B+	--	A
1.0	A-	C+	--	A
1.2	A-	C	--	A-
1.4	B+	D	A-	B+
Stall	B	D	B+	B-

[1]Controllability ratings:

A Good } Satisfactory
B Fair }

C Poor } Unsatisfactory
D Uncontrollable }

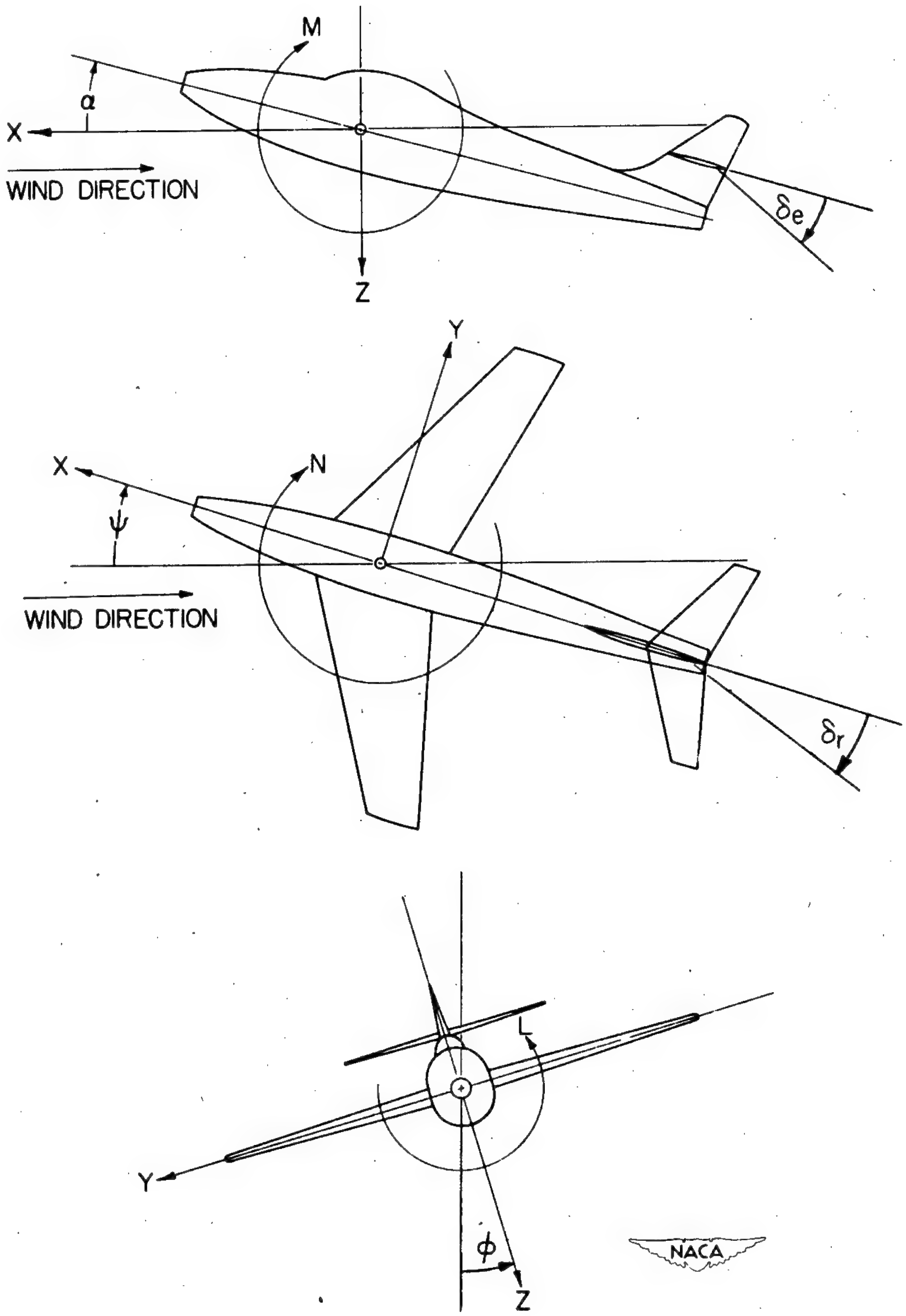

Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

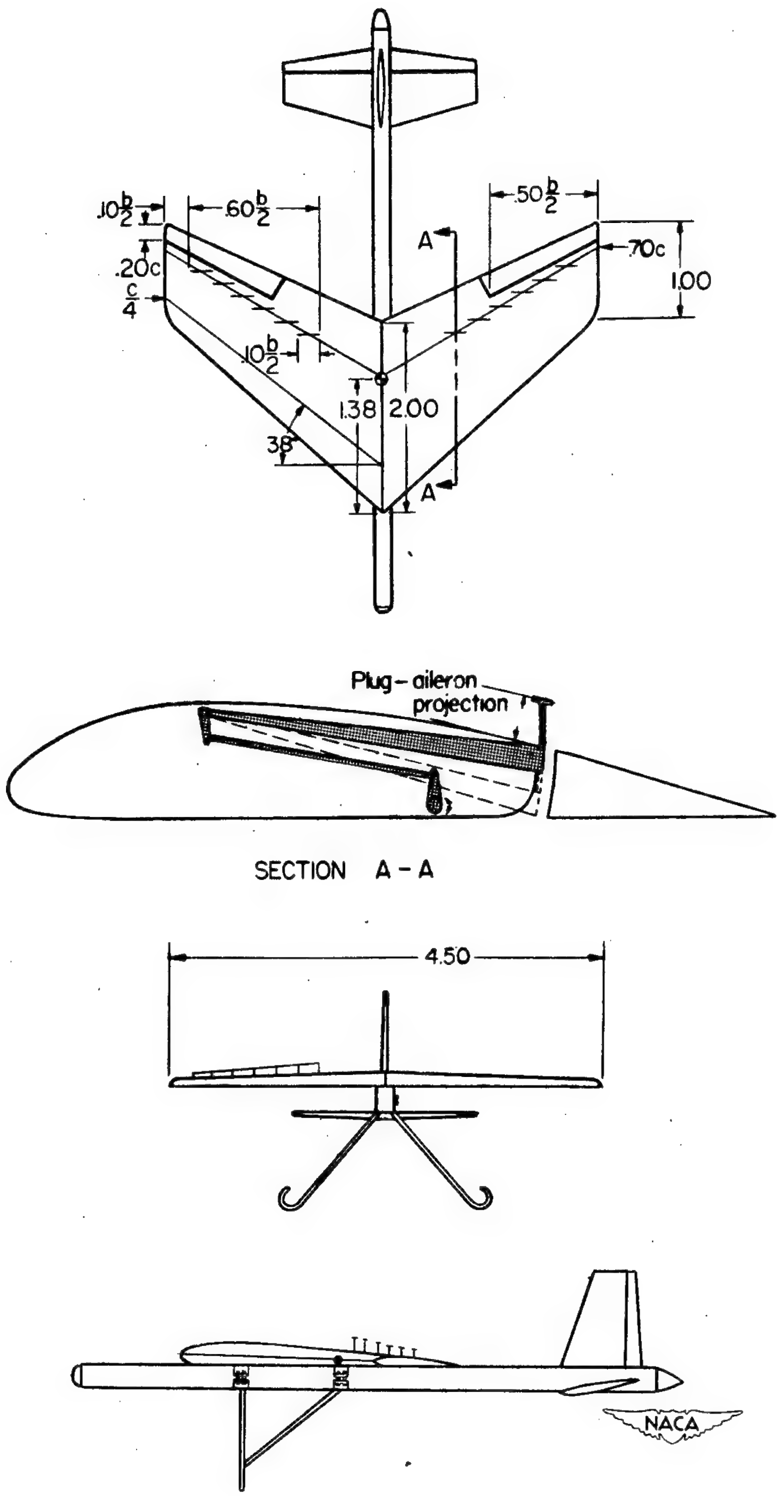

Figure 2.- Three-view sketch of free-flight-tunnel model and cross section of wing showing details of plug ailerons. All dimensions are in feet unless otherwise specified.

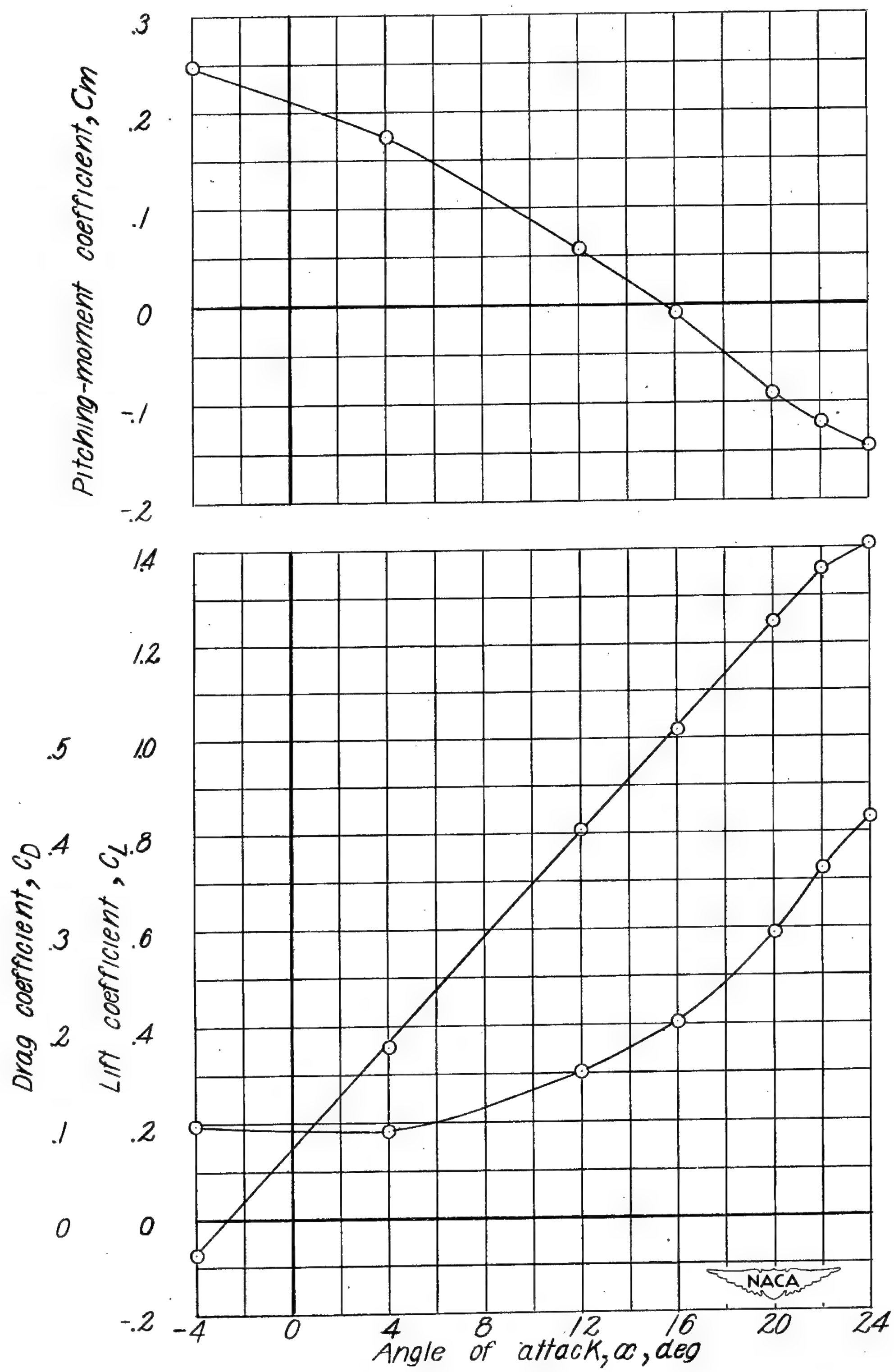

Figure 3.- Lift, drag, and pitching-moment characteristics of the model with all controls neutral.

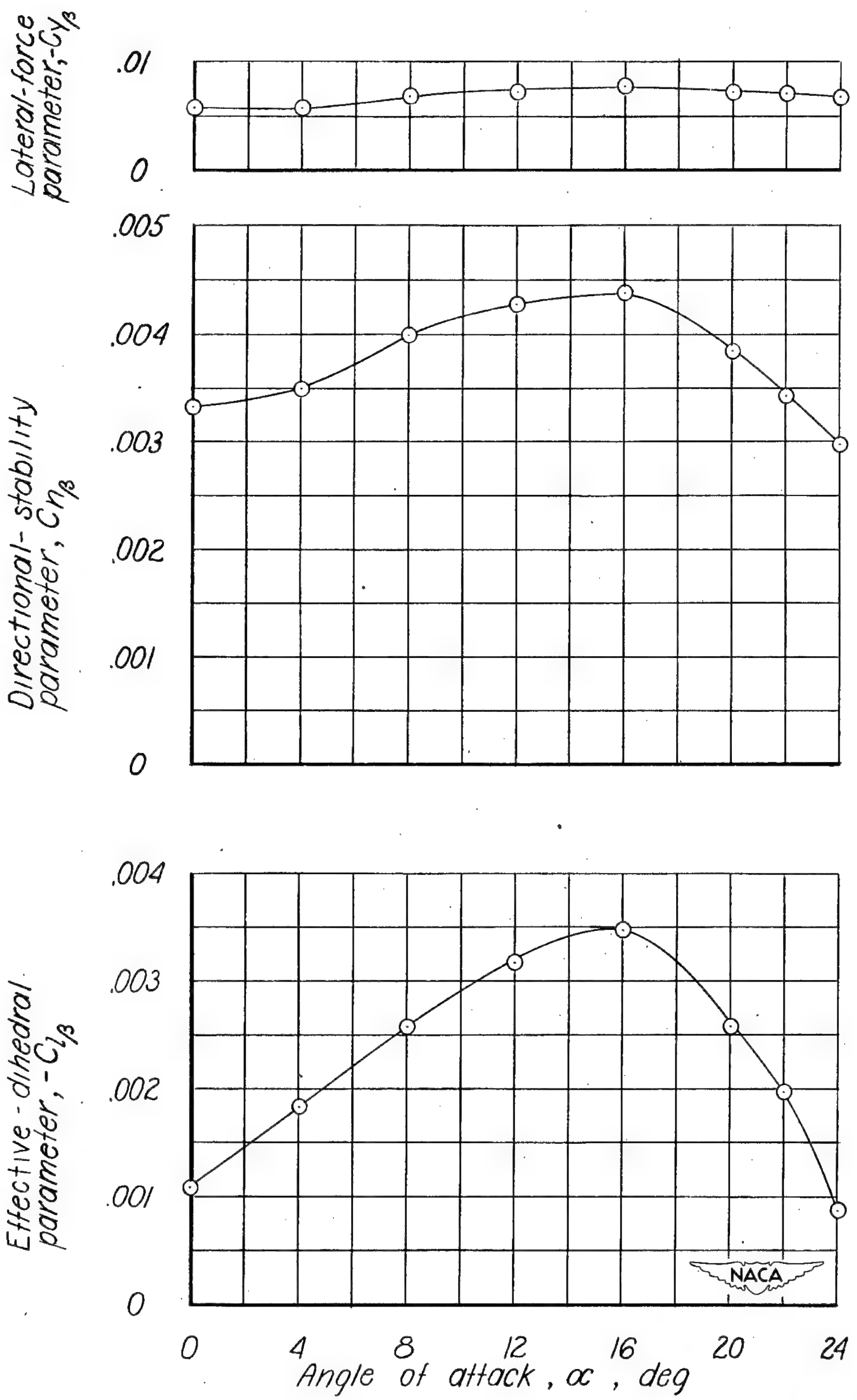

Figure 4.- Lateral stability characteristics of the model.

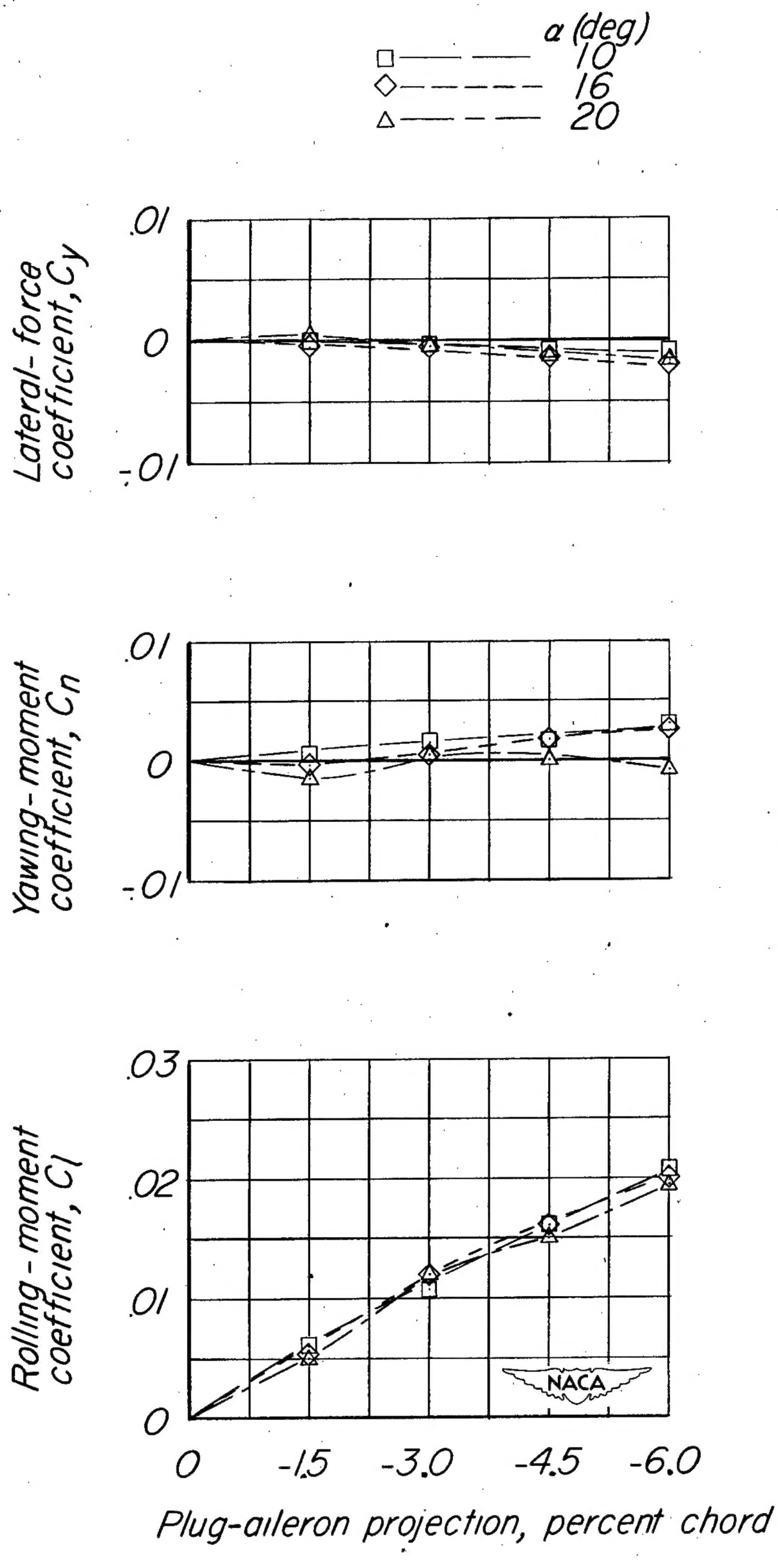

Figure 5.- Lateral control characteristics of the model with plug ailerons.

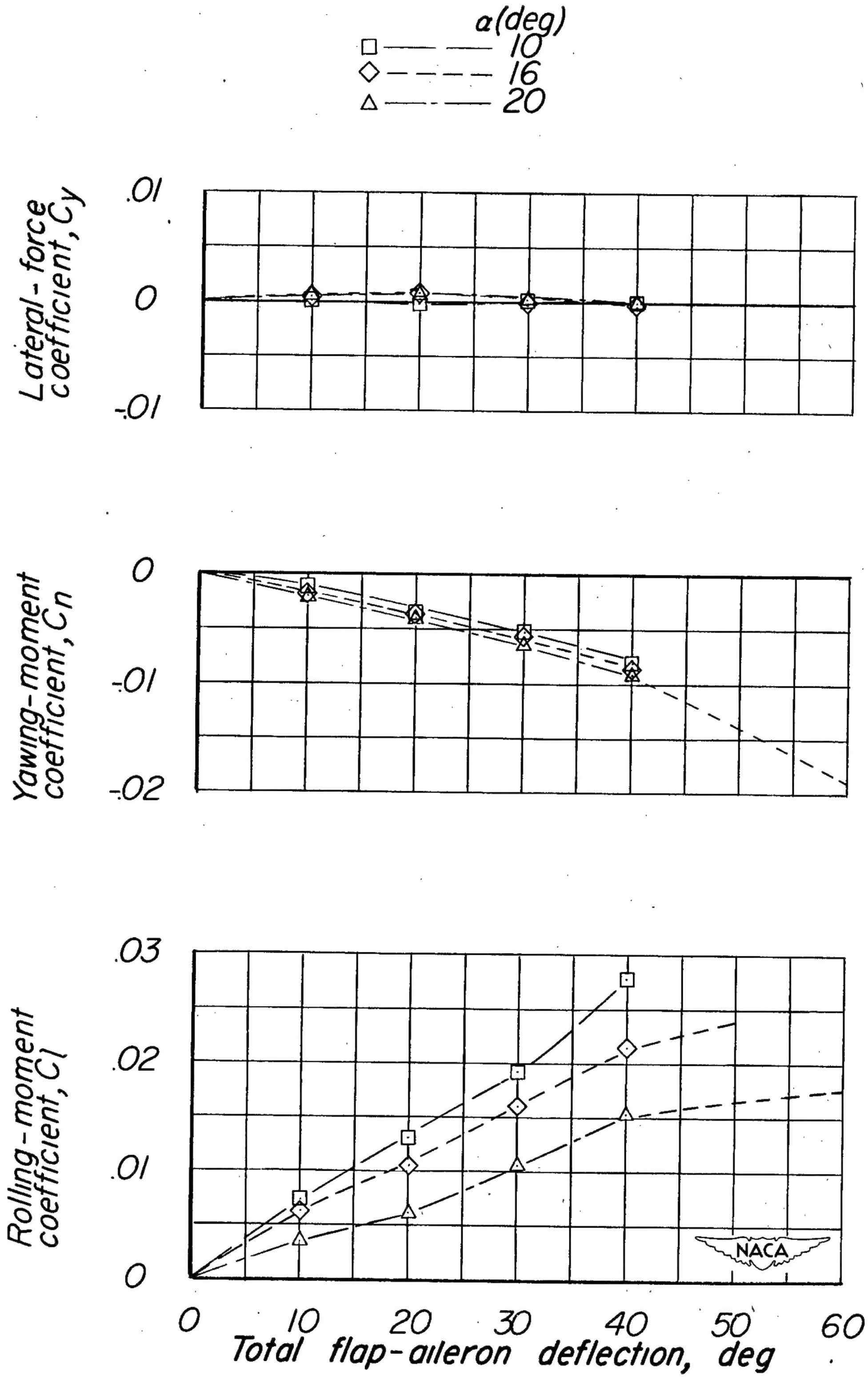

Figure 6.- Lateral control characteristics of the model with flap ailerons.

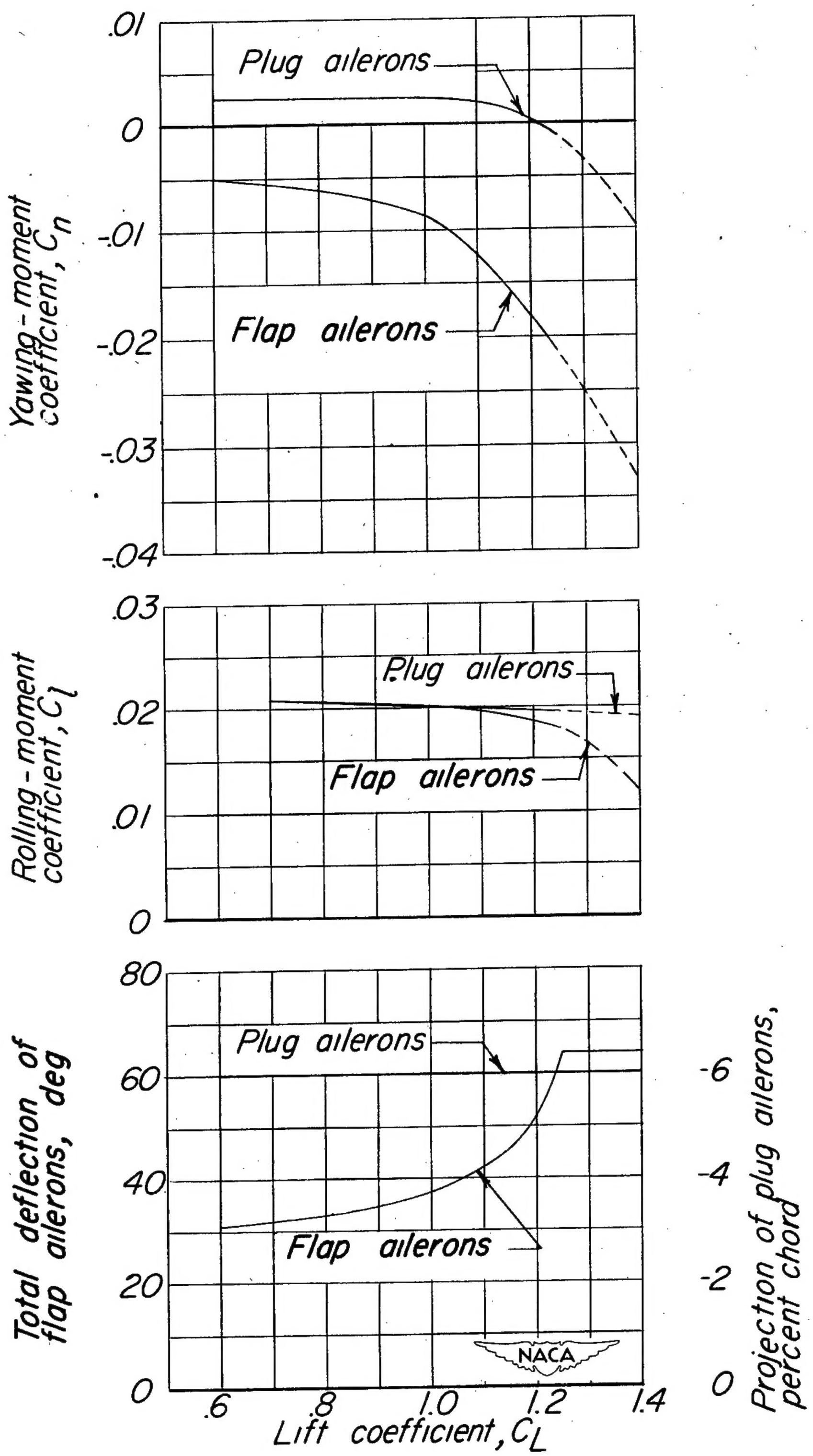

Figure 7.- Aileron deflections used in flight tests and rolling and yawing moments corresponding to these deflections.

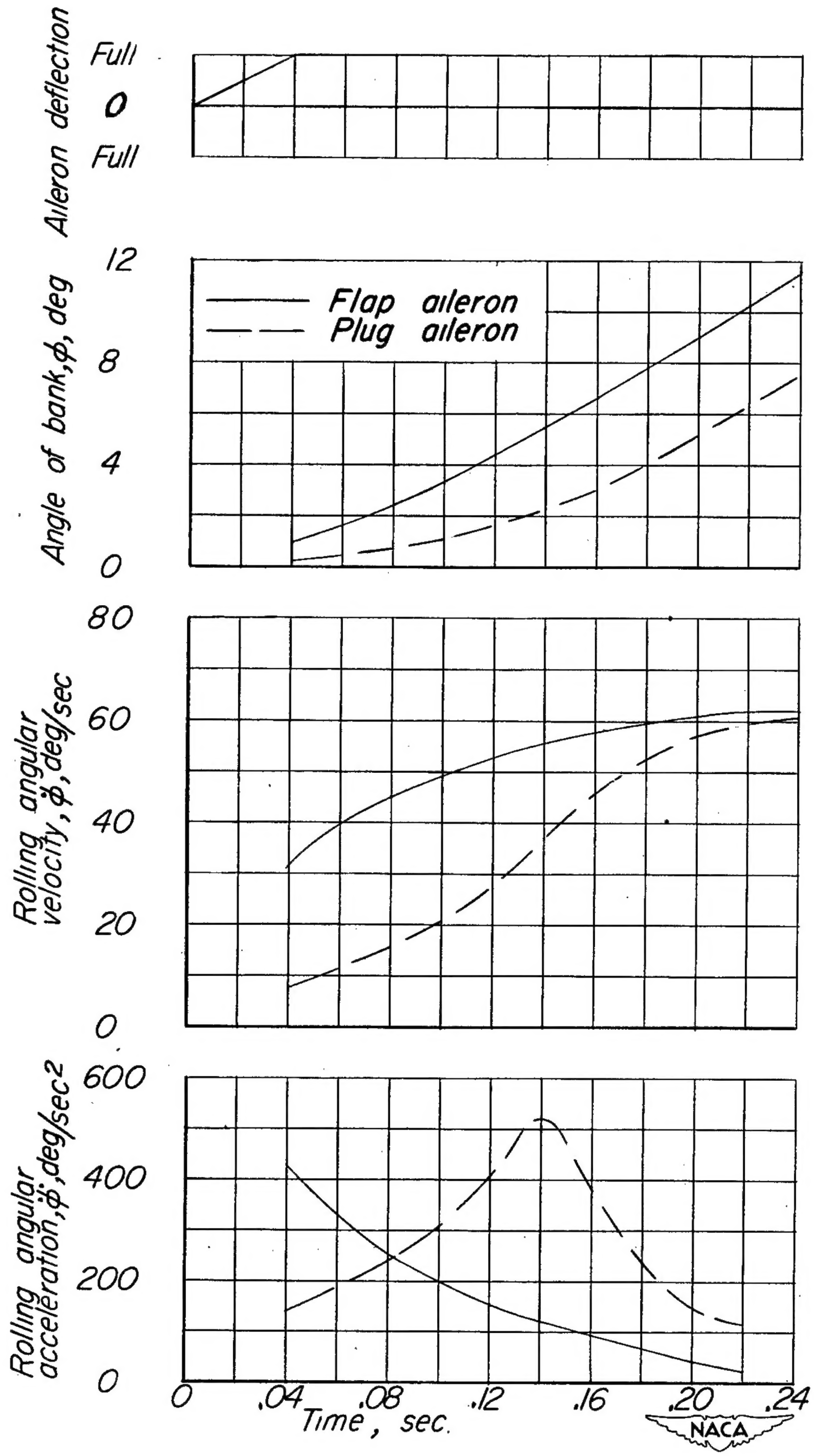

Figure 8.- Time histories of the angle of bank, rolling velocity, and rolling acceleration of the model due to aileron deflection. ($\alpha = 10^{\circ}$; $\delta_{a_{flap}} = 32^{\circ}$; $\delta_{a_{plug}} = -0.06c$; $\delta_r = 0$.)